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A First Generation Mathematical Model for Calculating Area of Influence and Potential Number of Animals Exposed to Management Programs

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ABSTRACT: Frequently, planning and authorization processes for a variety of management programs require estimates of size of the area or the potential number of animals that might be exposed to, or influenced by, the program(s) under consideration. A mathematical model, using animal density and average movement patterns as inputs, was developed and applied using coyote data from southern Texas. On the basis of this model, it appears that when the area encompassed by the management program is small relative to the average movements of the animals, animals in an area 10 to 50 times larger than the "application zone" may be affected. Even when the application zone is 40 times larger than the average home range, animals in an area 1.7 times larger than the management zone could be exposed. Ramifications and aspects for enhancing the reality of the model are discussed.

KEY WORDS: area of influence, *Canis latrans,* coyote, management effects, mathematical model, numbers of animals, removal

Mobility of free-ranging animals frequently results in the influence of management programs extending beyond the borders of the area to which the management program is applied. As a consequence, both the area and number of animals affected may be considerably larger than casually expected.

Although environmental impact statements (EISs), environmental assessments (EAs), and a variety of other program projections and evaluations frequently require estimates of the size of the area influenced and number of animals that might be affected by particular programs, standardized and defendable procedures for making such estimates are scarce. Such estimates are useful for anticipating the potential impact on "target" and "nontarget" species, can assist in developing management programs, or can aid in selecting among programs with different management approaches.

Our purpose here is to encourage the use of mathematical approaches for assessing bio-

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logic effects by providing an initial set of equations, a simple illustration, and a set of sample results. We also hope to encourage others to expand on these procedures.

Rationale

For our purposes, we consider any animal whose activity area lies entirely or partially within the boundaries of a management area to be *exposed* to the management program. While all animals within the management area at any specific time are exposed, some animals outside the management area at that time will also be exposed because part of their activity area lies within the management area. Thus, to assess the size of area influenced and potential number of animals affected, it becomes necessary to estimate (1) how far activity areas partially within the management area extend beyond the management zone and (2) the portion of animals in a zone around the management area that have activity areas extending into the management area.

Development of Equations

For ease of computation, we assume our animals have circular areas of activity that are stable (that is, there is no response by one animal to the fate or experience of another, neither ingress nor exploratory movements occur, and so forth). We also define the management area as being circular. The management area depicted in Fig. 1 is delineated by Circle A with Radius a. Concentric with A is another circle, C, with Radius c such that $c - a$ is the diameter of the average activity area of the animals. Animals outside C never enter the management zone because, by definition, they do not move linear distances greater than $c - a$ (that is, greater than the diameter of their activity area).

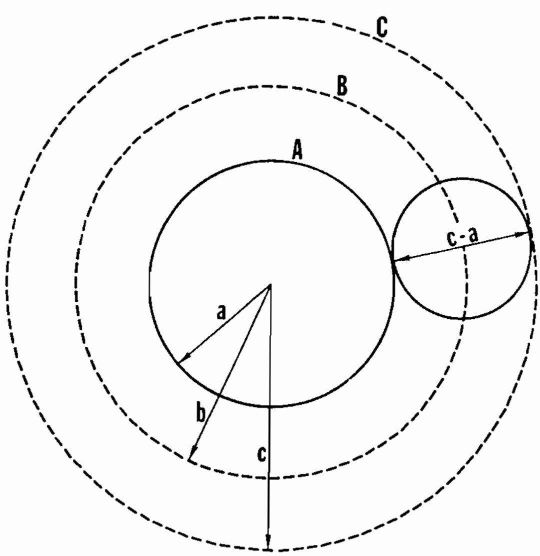

FIG. 1—*Diagrammatic representation of a management area, bounded by circle* A *with radius* a, *and an adjacent peripheral area, bounded by circle* C *with radius* c, *such that* c − a *equals the diameter of an average activity area for the animal of interest. Circle* B *is concentric with* A *and* C *and located half an activity area diameter (an activity area radius) outside of* A.

Area of Effect

The size of the management area, Circle A, is calculated as

$$S_A = \pi a^2$$

Similarly the potential area influenced by the management program (that is, the area inhabited by animals that have part of their activity area within the management area) can be defined as the area within C, equal to

$$S_C = \pi c^2$$

Number of Animals Exposed

Using an estimate of animal density, D, and assuming that animals are distributed uniformly, the number of animals within Circle A can be estimated with the equation

$$N_A = \pi a^2 D$$

Similarly, the number of animals in the peripheral area, $S_C - S_A$ can be estimated with the equation

$$N_{C-A} = \pi (c^2 - a^2) D$$

While all the animals comprising N_A are exposed to the management program, only a portion of those comprising N_{C-A} are exposed because some do not have an activity area that overlaps the management zone. Hence, the total number of animals exposed to the program, N_T, could be obtained by summing N_A and that portion *(P)* of N_{C-A} that have part of their activity area within A, or

$$N_T = \pi a^2 D + P\pi(c^2 - a^2)D$$

$$N_T = \pi D[a^2 + P(c^2 - a^2)]$$

P can be calculated, but the mathematics are cumbersome. The problem can also be resolved in terms of the centers of activity for the animals. By definition, animals with centers of activity $\leq$ one activity area radius outside the management area boundary, A, have activity areas that overlap part of the management area and, hence, are exposed to the management program, while those with centers of activity $\geq$ one activity radius outside of A are not. Thus, Circle B (with Radius b), concentric with and halfway between circles A and C (Fig. 1), encompasses the centers of all activity areas that partially or wholly overlap the management area. Because these centers of activity have a density and distribution identical to those of the animals, the potential number of animals exposed to the management program can be calculated by multiplying the density, D, by the area bounded by Circle B, or

$$N_T = \pi b^2 D$$

Sample Calculations

If a management program involves an attempt to remove all the coyotes from a manpopulation might be anticipated and perhaps the potential number of coyotes that could be removed. To illustrate the application of this model, we have chosen to use information from a very dense coyote population near Laredo, Texas [*1,2*]. As might commonly be encountered, this coyote population has two components with significantly different behavioral characteristics; in this case, transient and territorial individuals with much different space utilization patterns. Our solution is to make calculations for each component independently.

Estimates of density and mean sizes of areas of activity are used in the preceding equations to estimate the area over which some change in density might be anticipated, S_C, and the potential number of animals that could be removed, N_T, in removal programs on areas of 1, 5, 10, and 100 km^2, respectively, of comparable habitat (Table 1).

Resulting calculations suggest that under the conditions stated, and without any adjustments within the coyote population, the effects of coyote removal from an area of 1 km^2 might extend to an area 65 times larger. The relative size of the peripheral area decreases with larger management areas, but the total area affected is still 2.9 times larger than the management area when the program is applied to 100 km^2. Although coyote density indicates 2.0 coyotes on a 1-km^2 area at any one time, our calculations suggest over 23 coyotes routinely use the area. On management areas of 100 km^2, 1.5 times as many animals use the area compared to the number present at any particular time, as suggested by density estimates.

Even when the management area is 40 times greater than the average activity area of the animals under consideration, an area 1.7 times larger may be affected, and 1.3 times as many animals may be exposed as might be inferred solely on the basis of population density. Attempts at total removal of coyotes from moderate-sized areas of comparable habitat [*3,4*] suggest these models are not unrealistic.

TABLE 1—*Estimates of potential area of influence and number of coyotes exposed to management efforts applied to areas of four sizes.*

INPUT PARAMETERS [*1, 2*]		Behavioral Component of Coyote Population: Territorial Coyotes	Transient Coyotes	Total
Diameter of activity area ($c - a$, in km)		1.8	4.0	
Density (D, in number of animals/km^2)		1.3	0.7	2.0
CALCULATIONS				
Management Area Size, km^2	Radius of Management Area, km	Territorial Coyotes	Transient Coyotes	Total
		Area of Influence, S_C, km^2		
1	0.56	17	65	65
5	1.26	28	86	86
10	1.78	39	104	104
100	5.64	172	290	290
		No. of Animals Exposed, N_T		
1	0.56	9	14	23
5	1.26	19	23	42
10	1.78	29	31	61
100	5.64	174	128	303

TABLE 2—*Comparison of the sizes of areas influenced and numbers of animals exposed to management programs applied to 10-km² areas of various shapes.*[a]

Shape of Mgmt. Area	Length of Perimeter	Potential Size of Area Affected, km²	Potential No. of Animals Exposed
Circle	11.2	39	29
Triangle (equilat.)	14.4	45	33
Rectangle			
w × w (square)	12.6	42	30
w × 2w	13.4	43	31
w × 5w	16.9	49	35
w × 10w	22.0	58	41
w × 20w	29.7	72	50

[a] Mean activity area = 2.4 km² (diameter = 1.7 km). Animal density = 1.3/km².

Other Considerations

Use of circular and stable animal-activity and management areas in developing these equations is perhaps the simplest and most conservative situation, as demonstrated by results of similar calculations for areas of different shape (Table 2). In general, for management areas of similar size, the area affected increases in size as the length of the perimeter increases. Similarly, the relative number of animals with activity areas partially outside the management zone also increases.

The equations and preceding discussion assumed that *risk* could be assigned merely on the basis of whether or not the animal activity areas overlap the management area. In some instances, it might be more appropriate to assign risk based on the degree to which the animal activity areas overlap the management area. This would involve a separate set of equations but could incorporate nonuniform use of activity areas by the animals, changing vulnerabilities associated with differential behavior of animals in various portions of their activity areas [*5,6*], or different vulnerabilities for different segments of populations.

Incorporating a time element into the equations might make the calculations more realistic (and intimidating!) and would permit inclusion of other aspects of animal biology, such as exploratory movements [*7*], dispersal, ingress following animal removal, and effects associated with relative duration of management programs.

Much of the forgoing has been couched in terms of assessing the effects of management programs beyond the boundaries of the areas to which treatments might be applied. The same equations may be equally useful in defining treatment areas to create certain effects (for example, defining areas from which predators should be removed to protect a resource, like whooping crane nesting areas, or for planning vaccination programs to protect areas from wildlife-borne pathogens). In these instances, the focus is on defining a treatment area to provide some expected effect on a somewhat smaller management area.

Mathematical approaches to assessing the effects of management programs, as suggested here, more clearly identify the underlying assumptions and provide a more realistic basis for evaluating or projecting the influence of programs.

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